THE EFFECT OF SIMULATED HAIL DAMAGE DURING VARIOUS STAGES OF GROWTH ON THE YIELD OF WINTER WHEAT IN OKLAHOMA

ERIC GORDON STONE

Bachelor of Science

Oklahoma State University

1955

Submitted to the faculty of the Graduate School of the
Oklahoma State University in partial fulfullment of
the requirements for the degree of
MASTER OF SCIENCE
August 1964

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Thesis Approved:

A. M. Schlehuber

Thesis Adviser

Ben R Jackson

Billy B. Tucker

Dean of the Graduate School

ACKNOWLEDGMENTS

The author would like to express his sincere appreciation to his major advisor, Dr. A.M. Schlehuber, for his valuable suggestions and guidance during the course of the study, especially for his constructive criticism and correction in preparing the thesis.

The author is indebted to Dr. Robert D. Morrison and the staff of the computing center for assistance in the statistical analysis, also to Dr. Billy B. Tucker and Mr. Ben R. Jackson for their assistance in preparing the manuscript.

Grateful acknowledgment is expressed to Mr. Raymond A. Peck, Panhandle A. and M., for assistance in conducting the study. Also to the Small Grains Section of the Department of Agronomy for assistance in the planting, treating, harvesting, and threshing of the material used in this study.

Thanks is given particularly to the Oklahoma State University Agronomy Department and the Hail Insurance Adjustment and Research Association for the funds and material that made this study possible.

Special thanks is expressed to my wife, Creasia, for typing the manuscript and for her loving patience, understanding, and encouragement during the course of the study.

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INTRODUCTION

Hail is an important source of damage to winter wheat causing large annual losses in Oklahoma and other states. Wheat is the main cash crop in Oklahoma and the possible damage by hail is of real concern to the wheat producer. A comsiderable amount of the wheat crop is covered by insurance which makes up a large portion of the total crop hail insurance written in the state.

Experiments on the nature and extent of hail damage to growing crops have been conducted and reported by a number of investigators for a wide variety of crops.

The purpose of this experiment was to obtain additional information concerning the effect on yield by various treatments which simulate hail damage during various stages of growth. The information obtained will supplement the present information used by crop insurance companies for adjustment of losses.

REVIEW OF LITERATURE

Annual national losses to all crops caused by hail storms have been estimated above two hundred million dollars (14)[1/]. Eight to ten per cent of the crops in the western half of Oklahoma, especially the extreme west, is hailed out each year. Most of the hailstorms in Oklahoma occur in April, May, and June with nearly half occuring in May when the wheat is most susceptible to hail damage. A considerable amount of the loss by hail is covered by insurance. The average crop hail insurance rate for the state is about six dollars per one hundred dollars coverage and increases to about twelve dollars for the western part of the state (6).

As has been stated by Laude and Pauli (11), and certainly true, the determination of the crop loss is difficult; partially because undamaged areas of the crop growing under the same conditions of environment are not available for direct comparison. Some effects can be readily observed and evaluated, such as the number of stems cut off and the number of heads on the ground or hanging below the cutting line of the harvester. Other effects, such as loss of weight of grain in the head or loss in yield when leaves are destroyed, are not so readily observable.

1/ Numbers in parentheses refers to "Literature Cited" Page 31.

Snyder and Michelson (14) state that each crop has its own peculiarities of response to hail damage or simulated hail damage. Crops of different kinds differ in many respects, so the direct and possible indirect effects of hail damage for the various crops will also be different. Each crop must be studied individually.

In soybeans Camery and Weber (1) found that the loss of foliage reduces the yield more than stem breakage. In wheat Laude and Pauli (11) found that stem breakage reduces the yield more than loss of leaves, and Knowles (10) attributed a greater loss in yield to broken and bent stems than to bruised stems in wheat and other grain crops. Klages (9) found that injury to stems of flax caused a greater loss in yield than injury to leaves or loss of leaves.

Dungan's (2) four year study with hailstorm damage in corn showed differences in yield and quality of corn that were associated with several kinds of defoliation damage. Further studies (3) showed that the greatest losses occurred when damaged between the tasseling and fresh milk stages of growth.

The weather before and after the hail damage may play an important part in the recovery of the plants. This has been reported by a number of researchers and summarized by Snyder and Michelson (14). Since weather is an important factor, experiments in hail damage should be continued over a period of years.

Studies in simulated hail damage in small grains were conducted by Eldredge (5) at the Iowa Agricultural Experiment Station from 1930 to 1932, at a time when little information was available as to how different types of injury at the various stages of growth affected the yield.

Eldredge found that breaking the stems over as the heads begin to emerge reduced the yield about fifty per cent. There was a decrease in the injury at succeeding weekly internals until just before ripening when there was a reduction in yield of about ten per cent.

In an experiment on hail resistance among varieties of winter wheat at the Kansas Agricultural Experiment Station in 1939, Reitz (12) found that varieties differed significantly in reaction to hailstones as well as differing in reaction to cold, lodging, shattering, diseases, and various insects. There were a number of factors that appeared to cause variation in varieties: natural tendency to shatter, character of straw, stages of growth, recovery of plants, salvage of damaged crop, and size of hailstones and angle of impact. This experiment showed that varieties differed, but it also illustrated that more work was needed to show why they differed in reaction of hailstones. No references were found on further work on hail resistance since that time.

The most extensive research on simulated hail damage to winter wheat is a study at the Kansas Agricultural Experiment Station from 1949 to 1956 as reported by Laude and Pauli in 1959 (11). The results of this experiment showed that destruction of leaves more than six weeks before heading had no effect on grain yield. The loss of leaves in the boot stage reduced the yield 30 per cent. Smaller losses in yield resulted from the removal of leaves after heading. The loss in yield was associated with a decrease in the number of heads and the size of heads when the destruction of leaves occurred before the full boot stage. The destruction of leaves in the booting, heading, and later stages decreased the yield mainly by decreasing the size of kernels.

Twenty per cent loss in yield occurred when the lower part of the stem was broken in the booting stage. Yield losses increased to about 35 per cent for stem injury near the middle of the fruiting period. The loss in yield was less after this period with no reduction in yield when damaged just before harvest. Injury to the stems at the boot stage reduced number of kernels per head more than the size of kernels (11). Eldredge (5) obtained 50 per cent reduction in yield for stem breakage in the booting stage and a 10 per cent reduction in yield when damaged just before ripening.

The yields were not reduced as much by stem injuries above the flag leaf as by those lower on the plant. Injury in the boot stage above the head, including the flag leaf, caused a loss of about 25 per cent in yield. The amount of head trapping was not reported for this study (11).

As Laude and Pauli (11) state, the part of the wheat plant injured by hail and the extent of resulting damage depends much upon the stage of growth as well as upon the character and intensity of the hailstorm. This is true of many or perhaps most of the other crops. The critical stage of growth for hail damage to most crops that have been studied is the bloom stage and the period shortly after bloom (3, 4, 7, 8, 11, 13, 14, 16, 17). In flax the critical period is between bud formation and anthesis (9). In wheat the critical period is the boot and bloom stages (5, 11, 17), as indicated by the greatest loss of yield at these stages.

MATERIALS AND METHODS

The study was conducted on the Agronomy Research Station, Stillwater, Oklahoma. The variety of wheat used was Triumph (C. I. 12132)[2/]. The specific objectives of the study were to determine: (1) The effect of breaking the upper portion of the culms during the various stages of growth on the yield of winter wheat in Oklahoma. (2) The number of spikes on treated culms that drop off by combine ripe stage as compared with the number of spikes that remain on the treated culms. (3) The differences in kernel weight of grain produced on treated culms as compared with grain produced on untreated culms. (4) The difference in the number of kernels per head on treated culms as compared with the number on untreated culms.

The experimental design used was a randomized complete block with a factorial of treatments and replicated four times. Each plot consisted of four rows ten feet long with twelve inch row spacing.

At each of the five stages of growth, five treatments were applied. Boot stage only: (a) Check, (b) Break over one-third of the culms below the spike. (c) Break over three-thirds of the culms below the spike. (d) Break over one-third of the flag leaves above the spike. (e) Break over three-thirds of the flag leaves above the spike. When breaking over the flag leaf above the spike a paper clip was placed on the doubled-

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2/ C. I. Number refers to the accession number of the Field Crops Research Branch, ARS, USDA (formerly Cereal Investigations).

over flag leaf. This procedure was used to get as many trapped heads as possible. The trapping of heads in the boot stage is a very typically occurring result of hail damage. The hail breaks over the flag leaf above the spike trapping the awns in the break. The spike is then forced to emerge from the side of the sheath with the tip trapped and causing a curled, distorted spike.

Treatments at the bloom, milk, soft dough, and hard dough stages were: (a) Check, (b) Break over one-third of the culms below the flag leaf, (c) Break over three-thirds of the culms below the flag leaf, (d) Break over one-third of the culms above the flag leaf, (e) Break over three-thirds of the culms above the flag leaf.

The dates that the wheat was considered to be in each of the stages were: (a) boot, April 15, (b) bloom, April 22, (c) milk, May 4, (d) soft dough, May 16, (e) hard dough, May 21, (f) harvest, June 4.

Eight feet from each of the two center rows of each plot were harvested for yield. To determine the percentage of fallen heads for each plot, the fertile tillers from which the heads had dropped were counted in each harvested area and divided by the total fertile tillers in each harvested area. To determine the weight per 1,000 kernels, sufficient spikes were collected from the treated culms of the border rows of each plot to obtain 1,000 kernels per plot. To determine the number of kernels per spike, ten spikes were collected from the treated culms of the border rows of each plot.

In the analysis of the data the boot stage was analyzed separately because the treatments were slightly different from the later stages. At the boot stage the break was below and above the spike, while in the later stages the break was below and above the flag leaf. The boot stage was analyzed as five treatments in a randomized block with four replications. The other four stages were analyzed as a split plot in a randomized block with four replications. The main plots were stages and the subplots were treatments. The collected data were punched on IBM cards and processed through the IBM 650 type magnetic Drum Data Processing Machine. The L.S.D. was computed according to Steel and Torrie (15).

RESULTS AND DISCUSSION

Yield and Yield Components

Stages

The average grain yield ranged from 34.1 bushels per acre for all treatments applied at the boot stage (Table I) to 44.8 bushels per acre for all treatments applied at the soft dough stage (Table II). The greatest loss in grain yield occurred to wheat plants treated at the boot stage with the loss becoming less as the wheat reached maturity. This agrees with previous investigations (5, 11, 17) that wheat is very susceptible to hail damage in the boot and bloom stages. The difference among stages was significant at the 1% level of confidence (Table III). The yield at the bloom and milk stages were significantly different from the yield at the soft dough and hard dough stages. As shown in Table IV, the major portion of the total loss in grain yield at the boot stage was by the loss of heads. Also considerable loss in yield was caused by the loss in number of kernels per head. The major portion of the total loss in grain yield at the bloom and milk stages was by the loss in weight per 1,000 kernels. The major portion of the loss in grain yield at the hard dough stage was by the loss in number of heads per plot. The major portion of the loss in grain yield at the soft dough stage depended upon the treatment applied.

TABLE I

SUMMARY OF EFFECT OF TREATMENTS ON YIELD AND YIELD COMPONENTS STATISTICALLY SIGNIFICANT AT THE BOOT STAGE.

Treatments	Yield	Test Weight	Harvested Heads Per Plot	Percentage of Fallen Heads	Percentage of Trapped Heads
3/3 below spike	25.9	59.0	563	13.0	0.0
1/3 below spike	36.2	60.0	706	03.1	0.0
3/3 trapped	34.8	59.9	724	00.1	91.4
1/3 trapped	39.4	59.9	735	00.1	33.9
Average	34.1	59.7	682	04.1	31.3
Check	46.9	60.8	839	00.5	0.0
L.S.D. at 5% level	6.7	0.9	140.8	3.6	3.4
L.S.D. at 1% level	9.4	1.2	197.6	5.0	4.7

TABLE II

SUMMARY OF EFFECT OF TREATMENTS ON YIELD AND TEST WEIGHT FOR THE FLOWERING TO HARD DOUGH STAGES.

	Stages							
	Bloom		Milk		Soft Dough		Hard Dough	
Treatments	Yield bu./A	T.W. lb/bu	Yield bu/A	T.W. lb/bu	Yield bu/A	T.W. lb/bu	Yield bu/A	T.W. lb/bu
Break 3/3 above flag leaf	28.2	60.5	32.8	59.1	42.6	61.1	43.7	61.4
Break 1/3 above flag leaf	35.7	60.4	37.4	59.9	46.7	60.8	42.0	61.0
Break 3/3 below flag leaf	37.3	61.1	37.2	60.8	43.8	61.3	44.9	61.4
Break 1/3 below flag leaf	41.4	60.9	41.4	60.6	45.9	60.9	44.3	61.0
Average	35.7	60.7	37.2	60.1	44.8	61.0	43.7	61.0
Check	46.2	61.0	46.6	60.8	46.6	60.8	45.8	60.5

	L.S.D. at 5% level	at 1% level
Yield:		
Treatment	6.0	8.0
Stage	2.5	3.6
Test Weight:		
Treatment	0.6	0.8
Stage	0.2	0.4

TABLE III

ANALYSIS OF VARIANCE FOR YIELD AND YIELD COMPONENTS AT THE BLOOM THROUGH HARD DOUGH STAGES OF GROWTH WITH FIVE TREATMENTS AT EACH STAGE.

		Mean Square					
Source of Variation	df	Yield	Test Weight	No. of Heads Per Plot	Percentage of Fallen Heads	Average Kernels Per Head	Weight Per 1,000 Kernels
Replication	3	689.25**	2.23**	234,323.00**	7.49	13.30**	21.73**
Stages	3	266.35**	2.71**	29,355.33*	94.99**	5.80*	229.86**
Error-a	9	12.64	0.11	5,375.22	2.70	0.85	1.92
Treatments	4	198.50**	1.04**	12,046.00	64.42**	5.15	60.65**
Stage x Treatment	12	37.29*	0.72**	6,194.92	28.20**	2.66	23.19**
Error-b	48	17.70	0.17	6,664.31	1.26	2.19	0.92
Total	79						

* Significantly different at the 5% level.
** Significantly different at the 1% level.

TABLE IV

THE LOSS IN YIELD BY COMPONENTS AS COMPARED TO CONTROLS

	Total Grain Loss (%)	Loss of Heads (%)	Kernels Per Head (%)	Weight Per 1,000 Kernels (%)	Component Totals (%)
Boot					
B.1/3 C.B. Sp.	22.8	15.8	9.4	5.5	30.7
B.1/3 Fl.A.Sp.	16.0	12.5	5.1	4.7	22.3
B.3/3 C.B.Sp.	44.8	33.0	8.1	3.3	44.4
B.3/3 Fl.A.Sp.	25.8	13.7	6.8	1.4	21.9
Bloom					
B.1/3 C.B. Fl.	10.4	3.4	5.6	15.5	24.5
B.1/3 C.A. Fl.	22.7	11.8	9.4	26.4	47.6
B.3/3 C.B. Fl.	19.3	2.7	+2.1*	13.0	13.6
B.3/3 C.A. Fl.	39.0	22.0	+1.3	22.3	43.0
Milk					
B.1/3 C.B. Fl.	11.2	3.3	6.0	20.4	29.7
B.1/3 C.A. Fl.	19.7	4.6	3.2	27.5	35.3
B.3/3 C.B. Fl.	20.2	+1.8	5.6	20.7	24.5
B.3/3 C.A. Fl.	29.6	0.3	0.4	28.6	29.3
S. Dough					
B.1/3 C.B. Fl.	1.5	+1.3	+2.2	2.7	+0.8
B.1/3 C.A. Fl.	+0.2	+1.1	+8.0	3.8	+5.3
B.3/3 C.B. Fl.	6.0	2.4	+5.3	1.9	+1.0
B.3/3 C.A. Fl.	8.6	4.8	+10.2	0.0	+5.4
H. Dough					
B.1/3 C.B. Fl.	3.3	11.6	+4.8	+2.6	4.2
B.1/3 C.A. Fl.	8.3	10.4	+1.3	+1.7	7.4
B.3/3 C.B. Fl.	2.0	7.8	+3.0	+6.3	+1.5
B.3/3 C.A. Fl	4.6	7.8	+8.2	+5.1	+5.5

* Plus values are greater than control.

Treatments

The average grain yield per plot for the boot stage treatments ranged from 25.9 bushels per acre for breaking all of the culms below the spike to 46.9 bushels per acre for the check plot (Table I). Breaking of the culms below the spike was the more critical treatment at the boot stage for yield and all the components. When compared with the check, the loss of 45 per cent in yield by breaking all of the culms below the spike at the boot stage agrees reasonably well with the results of Eldredge (5), but does not agree with the results of Laude and Pauli (11) who reported a loss of about 20 per cent in yield when stems are damaged below the spike. Breaking the flag leaf above the spike at the boot stage reduced the yield about 25 per cent and agrees with that reported by Laude and Pauli (11).

The analysis of variance (Table V) shows that yield differences among treatments at the boot stage were significant at the 1% level. The L.S.D. values in Table I indicate that breaking all of the culms below the spike yielded significantly less than the other three treatments and the check.

The average yield per plot for the treatments used at the bloom through hard dough stages ranged from 28.2 bushels per acre for breaking all of the culms above the flag leaf at the bloom stage to 46.7 bushels per acre for breaking one-third of the culms above the flag leaf at the soft dough stage (Table II). The breaking of the culms above the flag leaf was more detrimental and caused a greater loss in yield than the breaking of the culms below the flag leaf. The analysis of variance (Table III) shows that differences among treatments at bloom through

TABLE V

ANALYSIS OF VARIANCE FOR YIELD AND YIELD COMPONENTS AT THE BOOT STAGE OF GROWTH WITH FIVE TREATMENTS.

		Mean Square						
Source of Variation	df	Yield	Test Weight	No. of Heads Per Plot	Percentage of Fallen Heads	Average Kernels Per Head	Weight Per 1,000 Kernels	Percentage of Trapped Heads
Replications	3	104.30*	0.57	39,324.33*	5.57	0.69	5.00	7.20
Treatments	4	233.45**	1.55*	39,223.25*	122.97**	3.08	2.56	6,366.91**
Error	12	18.76	0.33	8,339.08	5.30	1.19	1.64	4.82
Total	19							

* Significantly different at the 5% level.
** Significantly different at the 1% level.

hard dough stages were significant at the 1% level. The only treatment statistically different from the others at the 1% level was breaking all of the culms above the flag leaf at the bloom stage (Table II). The stage x treatment interaction was significant at the 5% level, which indicates that the treatments did not respond in the same manner at all stages.

Just as a plant is made up of component parts such as leaves, stems, roots, etc. grain yield is made up of "yield components". In wheat, the number of tillers with fertile spikes, the number of seeds per spike, and the average weight of kernels per unit of area are the three grain yield components generally considered in the literature as comprising the chief factors. In Table VI, the data from Table IV have been reorganized to show the relative (on a percentage basis) gains and losses of the yield components to total grain loss as compared to the controls for each stage and treatment. In the upper portion of the table, the nine stages and treatments in which the total yield components exceeded the actual grain loss are listed. In the lower portion of the table the treatments in which the grain loss exceeded the total of the yield components are listed. For example, the grain yield of the treatment of breaking one-third of the culms below the spike in the boot stage yielded only 36.2 bushels, (77.2%) of the control, a loss of 22.8 %. The yield component losses were: 15.8% in loss of heads; 9.4% in number of kernels per head; and 5.5% in weight per 1,000 kernels, a total of 30.7%. The difference, 7.9%, constitutes the discrepancy between the losses in total yield components as compared to the observed yield loss.

TABLE VI

GRAIN LOSSES COMPARED TO ADDITIVE LOSSES OF YIELD COMPONENTS BASED ON RELATIVE VALUES OF CONTROLS

No.	Treatment	Component Total		Grain Loss	Difference
1.	Boot-1/3 culms below spike	30.7	-	22.8=	7.9
2.	Boot-1/3 flag leaves above spike	22.3	-	16.0=	6.3
5.	Bloom-1/3 culms below flag leaf	24.5	-	10.4=	14.1
6.	Bloom-1/3 culms above flag leaf	47.6	-	22.7=	24.9
8.	Bloom-3/3 culms above flag leaf	43.0	-	39.0=	4.0
9.	Milk-1/3 culms below flag leaf	29.7	-	11.2=	18.5
10.	Milk-1/3 culms above flag leaf	35.3	-	19.7=	15.6
11.	Milk-3/3 culms above flag leaf	24.5	-	20.2=	4.3
17.	H. Dough-1/3 culms below flag leaf	4.2	-	3.3=	0.9
		Grain Loss		**Component Total**	**Difference**
3.	Boot-3/3 culms below spike	44.8	-	44.4=	0.4
4.	Boot-3/3 flag leaves above spike	25.8	-	21.9=	3.9
7.	Bloom-3/3 culms below flag leaf	19.3	-	13.6=	5.7
12.	Milk-3/3 culms above flag leaf	29.6	-	29.3=	0.3
13.	S. Dough-1/3 culms below flag leaf	1.5	+	0.8=	2.3
14.	S. Dough-1/3 culms above flag leaf	+0.2	+	5.3=	5.1
15.	S. Dough-3/3 culms below flag leaf	6.0	+	1.0=	7.0
16.	S. Dough-3/3 culms above flag leaf	8.6	+	5.4=	14.0
18.	H. Dough-1/3 culms above flag leaf	8.3	-	7.4=	0.9
19.	H. Dough-3/3 culms below flag leaf	2.0	+	1.5=	3.5
20.	H. Dough-3/3 culms above flag leaf	4.6	+	5.5=	10.1

As shown in Table VI about one half of the treatments had a grain loss greater than the total of the yield components and the other half had a greater total component loss than the grain loss. At the boot stage there was a greater total loss in yield components than in the loss of grain yield for the one-third breakage treatments (Nos. 1 and 2). There was a greater loss in grain yield than in the total loss in yield components at the boot stage when all of the culms or flag leaves were broken (Nos. 3 and 4). At the bloom and milk stages three of the four breakage treatments at each stage, one-third of the culms below and above the flag leaf, and all of the culms above the flag leaf, had a greater loss in yield components than in the loss of grain yield. At the soft dough stage all of the breakage treatments had a greater loss in grain yield than in the total loss in components. At the hard dough stage three of the four breakage treatments, one-third of the culms above the flag leaf and all of the culms below and above the flag leaf, had a greater loss in grain yield than in total loss of yield components. The treatment (No. 6) with the greatest difference between loss in grain yield and yield components is breaking one-third of the culms above the flag leaf at the bloom stage. The loss by the components was 25 per cent higher than the grain loss. The treatment with the least difference between grain loss and loss in components was breaking all of the culms above the flag leaf at the milk stage (No. 12). The grain loss was only 0.3 per cent higher than the component total. At the soft dough and hard dough stages many of the components actually had a gain over the check rather than a loss. The bloom and milk stages had the greatest differences between grain loss and loss by components with the loss by components being greater than the loss in grain yield.

In 8 of the 20 treatments the relative differences between the observed grain losses and yield component losses was under 5%; in 14 out of 20 the discrepancy was under 10%; and in only 3 out of 20 the difference was over 15% (15.6% for No.12, 18.5% for No.9, and 24.9% for No.6). The reasons for the larger differences are not apparent at this time, unless it is due to sampling error. Theoretically, the "input" (yield components) should equal the "output" (yield).

As shown in Tables IV and VI, the greater losses in yield occurred at the boot stage with breaking all of the culms below the spike and at the bloom stage with breaking all of the culms above the flag leaf. The breaking of the culms above the flag leaf was more detrimental and caused a greater loss in yield than breaking of the culms below the flag leaf at the bloom through hard dough stages. This is the opposite of the results as reported by Laude and Pauli (11). They reported that stem injuries below the flag leaf reduced yield more than stem injuries above the flag leaf.

Test Weight

Stages

The average test weight for stages ranged from 59.7 pounds per bushel for the boot stage (Table I) to 61.0 pounds per bushel for the soft dough and hard dough stages (Table II). The difference among stages for test weight was highly significant (Table III). The L.S.D. indicates that the milk stage was significantly different from the other stages.

Treatments

The average test weight for treatments ranged from 59.0 pounds per bushel for breaking all of the culms below the spike at the boot stage (Table I) to 61.4 pounds per bushel for breaking all of the culms below as well as above the flag leaf at the hard dough stage (Table II). Test weight which would be expected to correspond to kernel weight, was highly significant among treatments for the bloom through hard dough stages, but was significant at the 5% level at the boot stage. The stage x treatment interaction for test weight was significant at the 1% level (Table III), which indicates that the treatments did not respond in the same manner at all stages.

Number of Heads Harvested Per Plot

Stages

The average number of heads harvested per plot ranged from 682 for the boot stage to 826 for the soft dough stage (Tables I and VII). The boot and bloom stages had the lowest number of heads per plot in the harvest area. The number of heads per plot is almost linear with the yield at each stage. As the number of heads increase the yield increases. The analysis of variance for number of heads per plot (Table III) shows that the difference among stages was significant at the 5% level. The milk and soft dough stages were significantly different from the other stages.

Treatments

The average number of heads harvested per plot for the boot stage treatments ranged from 563 for breaking all of the culms below the spike

TABLE VII

SUMMARY OF NUMBER OF HEADS HARVESTED PER PLOT AND PERCENTAGE OF FALLEN HEADS FOR THE FLOWERING TO HARD DOUGH STAGES.

	Stages							
	Bloom		Milk		Soft Dough		Hard Dough	
Treatments	No. Heads	%Fallen Heads	No. Heads	%Fallen Heads	No. Heads	%Fallen Heads	No. Heads	%Fallen Heads
Break3/3 above flag leaf	626	14.8	821	3.3	793	1.1	787	1.8
Break1/3 above flag leaf	708	7.0	786	2.3	843	0.6	765	0.7
Break3/3 below flag leaf	782	3.3	839	0.4	813	0.8	787	1.0
Break1/3 below flag leaf	776	1.0	797	0.8	844	0.5	755	0.4
Average	723	6.5	811	1.7	826	0.8	773	1.0
Check	803	0.3	824	0.5	834	0.3	854	0.0

No. of Heads:	L.S.D. at 5% level	at 1% level
Treatments	116.0	154.7
Stages	52.4	75.3
%Fallen Heads:		
Treatment	1.6	2.1
Stages	1.2	1.7

TABLE VIII

SUMMARY OF KERNELS PER HEAD AND WEIGHT PER 1,000 KERNELS FOR THE FLOWERING TO HARD DOUGH STAGES.

	Stages							
	Bloom		Milk		Soft Dough		Hard Dough	
Treatments	Kern. Per Head	Wt. Per 1,000 Kern.	Kern. Per Head	Wt.Per 1,000 Kern.	Kern. Per Head	Wt.Per 1,000 Kern.	Kern. Per Head	Wt.Per 1,000 Kern.
	(No.)	(Grms.)	(No.)	(Grms.)	(No.)	(Grms.)	(No.)	(Grms.)
3/3 above f.l.	23.7	28.6	24.7	26.2	24.9	36.6	25.0	36.9
1/3 above f.l.	21.2	27.1	24.0	26.6	24.4	35.2	23.4	35.7
3/3 below f.l.	23.9	32.0	23.4	29.1	23.8	35.9	23.8	37.3
1/3 below f.l.	22.1	31.1	23.3	29.2	23.1	35.6	24.2	36.0
Average	22.7	29.7	23.9	27.8	24.1	35.8	24.1	36.5
Check	23.4	36.8	24.8	36.7	22.6	36.6	23.1	35.1

Kernels Per Head:	L.S.D. at 5% level	at 1% level
Treatment	2.11	2.81
Stage	.66	.94
Weight Per 1,000 Kernels:		
Treatment	1.37	1.82
Stage	.99	1.43

to 839 for the check plot (Table I). The analysis of variance for number of heads per plot (Table V) shows that the difference among treatments was significant at the 5% level. The only treatment significantly different from the other four at the boot stage was breaking all of the culms below the spike (Table I). The breaking of the culms below the spike was more detrimental than breaking the flag leaf above the spike. The breaking of the culms below the spike caused considerable sterility which resulted in a much smaller number of fertile heads per plot. The breaking of the culms below the spike also caused a large number of fallen heads which contributed to the smaller number of heads harvested per plot.

There was some recovery of the plants by a turning up at the node above the break. Many of the spikes did not completely emerge from the sheath.

The average number of heads harvested per plot for the treatments used at the bloom through hard dough stages ranged from 626 for the treatment breaking all of the culms above the flag leaves at the bloom stage to 854 for the check at the hard dough stage (Table VII). The difference in treatments for these four stages was not significant. The treatments breaking all of the culms below the flag leaves at the milk stage; breaking one-third of the culms above, and breaking one-third of the culms below the flag leaf at the soft dough stage exceeds the check plots.

Percentage of Fallen Heads Per Plot

Stages

The average percentage of fallen heads per plot ranged from 0.8 for the soft dough stage to 6.5 for the bloom stage (Table VII). The analysis of variance for the percentage of fallen heads (Tables III and V) shows that the difference among stages was significant at the 1% level. The bloom stage was significantly different from the milk, soft dough, and hard dough stages. The boot and bloom stages were the most critical from the standpoint of percentage of fallen heads. The loss of heads accounts for the major portion of the total loss in yield at the boot stage (Table IV), but not for the bloom stage. The percentage of fallen heads is an important loss at the bloom stage, but the greatest loss in yield at this stage is caused by loss in weight per 1,000 kernels.

Treatments

The average percentage of fallen heads per plot at the boot stage ranged from 0.1 for the trapped heads treatment to 13.0 for breaking all of the culms below the spike (Table I). The analysis of variance for percentage of fallen heads (Table V) shows that the difference among treatments at the boot stage was significant at the 1% level. Breaking all of the culms below the spike was significantly different from the other four treatments as shown by the L.S.D. in Table I. The breaking of the culms below the spike caused considerably greater loss of heads than breaking the flag leaves above the spike.

The average percentage of fallen heads per plot for the treatments used at the bloom through hard dough stages ranged from 0.0 for the check at the hard dough stage to 14.8 for the treatment breaking all of the culms above the flag leaf at the bloom stage (Table VII). The analysis of variance (Table III) shows that difference among treatments was significant at the 1% level. Breaking one-third and three-thirds of the culms above the flag leaf were significantly different from the check, breaking one-third, and three-thirds below the flag leaf at the bloom and milk stages (Table VII). There was no significant difference in treatments at the soft dough and hard dough stages.

The breaking of the culms above the flag leaf caused a greater loss of heads than breaking the culms below the flag leaf. The decrease in yield was linear with the increase in number of fallen heads. The interaction of stages and treatments was highly significant (Table III). The treatments with the higher per cent of fallen heads were at the boot and bloom stages, which had the higher percentage of fallen heads.

Number of Kernels Per Head

Stages

The average number of kernels per head ranged from 22.7 for the bloom stage to 24.1 for the soft dough and hard dough stages (Table VIII). The boot stage, with 22.1 kernels per head (data not shown), was slightly less than the bloom stage. The greatest loss in number of kernels per head occurred at the boot stage and caused a greater loss in yield at the boot stage than at the other stages of growth (Table IV). There was a gain in kernels per head at the soft dough and hard dough stages which helped to offset the loss by other components. The analysis of variance (Table III) shows that the difference among stages was significant at the 5% level. The bloom stage was significantly different from the milk, soft dough, and hard dough stages.

Treatments

The number of kernels per head for the treatments used at the boot stage, (data not shown), ranged from 21.3 for the treatment of breaking one-third of the culms below the spike to 23.5 for the check treatment. The number of kernels per head for the treatments at the bloom through hard dough stages ranged from 21.2 for the treatment of breaking one-third of the culms above the flag leaf at the bloom stage to 25.0 for breaking all of the culms above the flag leaf at the hard dough stage Table VIII. The analysis of variances (Tables III and V) shows that differences among treatments for number of kernels per head was not significant.

Weight Per 1,000 Kernels

Stages

The average weight per 1,000 kernels ranged from 27.8 grams for the milk stage to 36.5 grams for the hard dough stage (Table VIII). The bloom and milk stages had the lowest weight per 1,000 kernels and was the principal loss in yield at these stages (Table IV). The kernel weight was little affected at the boot, soft dough, and hard dough stages. The analysis of variance (Table III) shows that the difference among stages for weight per 1,000 kernels was significant at the 1% level. The bloom and milk stages were significantly different from the other stages. The great loss of kernel weight at the bloom stage agrees with the results of Laude and Pauli (11) for stem injury.

Treatments

The analysis of variance (Table V) shows that the difference among treatments for weight per 1,000 kernels at the boot stage was not significant at the 1% or 5% level. The average weight per 1,000 kernels for the treatments used at the bloom through hard dough stages ranged from 26.2 grams for the treatment breaking three-thirds of the culms above the flag leaf at the milk stage to 37.3 grams for the treatment breaking three-thirds of the culms below the flag leaf at the hard dough stage (Table VIII). The analysis of variance (Table III) shows that the difference among treatments for weight per 1,000 kernels was significant at the 1% level. The check plot was significantly different from the other treatments at the bloom and milk stages; and the treatments of breaking above the flag leaf was significantly different from the other treatments at the bloom and milk stages (Table VIII). The interaction of stage x treatment was significant at the 1% level (Table III) indicating that the treatments did not respond the same at all stages. The treatments which produced the highest weight per 1,000 kernels, breaking all of the culms below the flag leaf and all of the culms above the flag leaf, were at the soft dough and hard dough stages. The treatments which produced the lowest weight per 1,000 kernels, breaking the culms above the flag leaf, were at the milk stage.

Percentage of Trapped Heads

The analysis of variance (Table V) shows that the difference among treatments for percentage of trapped heads at the boot stage was significant at the 1% level as would be expected with only two of the five treatments having trapped heads. Fully one-third of the spikes were trapped for the treatment breaking one-third of the flag leaves above the spike. Ninety-one per cent of the spikes were trapped for the treatment breaking all of the flag leaves above the spike.

Replications

The difference among replications was significant at the 5% level at the boot stage for yield and the average number of heads per plot (Table V). The difference among replications was significant at the 1% level of confidence in the later stages for yield, the average number of heads per plot, average kernels per head, weight per 1,000 kernels, and test weight (Table III). The third replication was lower for every factor except the percentage of fallen heads and weight per 1,000 kernels (Table IX).

Precipitation

According to Table X the rainfall was above normal for the year. The August rainfall was below normal, but by the time the wheat was planted in October the total rainfall to that time was 5.42 inches above normal. The November, December, January, February, and May rain-falls were also below normal, but during November through February the wheat was not so actively growing. The remainder of the growing season was near normal and caused no visible moisture stress to the crop.

TABLE IX

A SUMMARY OF THE AVERAGE VALUES FOR COMPONENTS BY REPLICATIONS

Replications	No. of Heads Per Plot	Percentage of Fallen Heads	Kernels Per Head	Weight Per 1,000 Kernels	Yield	Test Weight
1	822.1	1.6	24.4	33.1	44.5	60.8
2	810.4	2.8	23.2	33.1	42.5	60.8
3	623.0	2.2	22.7	35.1	32.3	60.1
4	848.4	2.7	23.0	33.0	42.9	60.5

TABLE X

SUMMARY OF THE MONTHLY PRECIPITATION FOR
THE PERIOD JUNE 1, 1962-May 31, 1963.
RAINFALL (inches)

Month	Received	Average	Deviation
June	6.20	4.24	1.96
July	4.99	3.53	1.46
August	1.36	3.21	-1.85
September	7.23	3.38	3.85
October	4.76	2.78	1.98
November	1.24	1.85	-0.61
December	1.18	1.34	-0.16
January	0.44	1.16	-0.72
February	0.06	1.35	-1.29
March	2.91	1.86	1.05
April	3.18	2.86	0.32
May	3.78	4.62	-0.84
	37.33	32.18	5.15

Total for the year 37.33.
Total Oct 1-May 31 17.55.

SUMMARY

An experiment was initiated to determine the effects on yield and yield components of winter wheat by breaking the upper portion of the culms during the various stages of growth. Five treatments were used at each of the five stages of growth. One variety, Triumph, was used in the experiment.

The highest yield obtained was 46.9 bushels per acre for the check which was used for comparing the treatments in the boot stage. The lowest yield obtained was 25.9 bushels per acre for the treatment of breaking three-thirds of the culms below the spike at the boot stage. The next lowest yield was 28.2 bushels per acre for the treatment of breaking three-thirds of the culms above the flag leaf at the bloom stage. In general, the greater losses were in the earlier stages and in the more severe treatments of breaking three-thirds of the culms. As the wheat reached maturity the losses tended to be less. At the boot stage the loss was greater with treatment below the spike than above the spike. At the bloom through hard dough stages the loss was greater with treatment above the flag leaf than below the flag leaf with the exception of breaking one-third of the culms above the flag leaf at the soft dough stage which was also higher than the check. This was probably due to the greater number of fertile tillers and the greater number of kernels per head than in the check.

At the boot stage the greater loss in yield was caused by loss of heads and sterile spikes when the culms were broken below the spike. At the bloom stage the greater loss in yield was caused by loss of heads and loss in weight per 1,000 kernels. At the milk and soft dough stages the greatest loss in yield was caused by the loss in weight per 1,000 kernels. At the hard dough stage the greatest loss in yield was caused by loss in number of heads per plot. The type of loss varied considerably depending upon the stage of growth when the treatment was applied.

The precipitation was above normal at Stillwater for the crop year and the distribution was relatively good. There was no visible moisture stress during the active growing season.

The experiment should be continued to determine the effect that different years have upon the yield and extent of damage by the various treatments at the various stages. Since environment plays an important part in the extent of damage and in the amount of recovery, there could be a considerable difference between years, if climatic differences are great.

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VITA

Eric Gordon Stone

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF SIMULATED HAIL DAMAGE DURING VARIOUS STAGES OF GROWTH ON THE YIELD OF WINTER WHEAT IN OKLAHOMA

Major Field: Agronomy (Field Crops)

Biographical:

Personal Data: Born September 16, 1931 at Blackwell, Oklahoma, the son of Philip and Elsie Stone. Married Creasia Germany, January 24, 1954.

Education: Attended elementary school near Blackwell and graduated from Blackwell High School, Blackwell, Oklahoma, in 1949. Undergraduate study at Oklahoma State University, 1950-1955. Received Bachelor of Science degree in Agronomy, May 1955. U. S. Air Force Pilot Training School, 1955-1956. Graduate study at Oklahoma State University, 1961-1964.

Experience: Born and reared on a farm. Officer in U.S. Air Force, 1955-1960. Student-Assistant, Oklahoma Foundation Seed Stocks Inc., Oklahoma State University, 1961-1963. Graduate-Assistant of the Agronomy Department, Oklahoma State University, 1963-1964.

Organizations: American Society of Agronomy and Crop Science Society of America.

Date of Final Examination: August 1964.